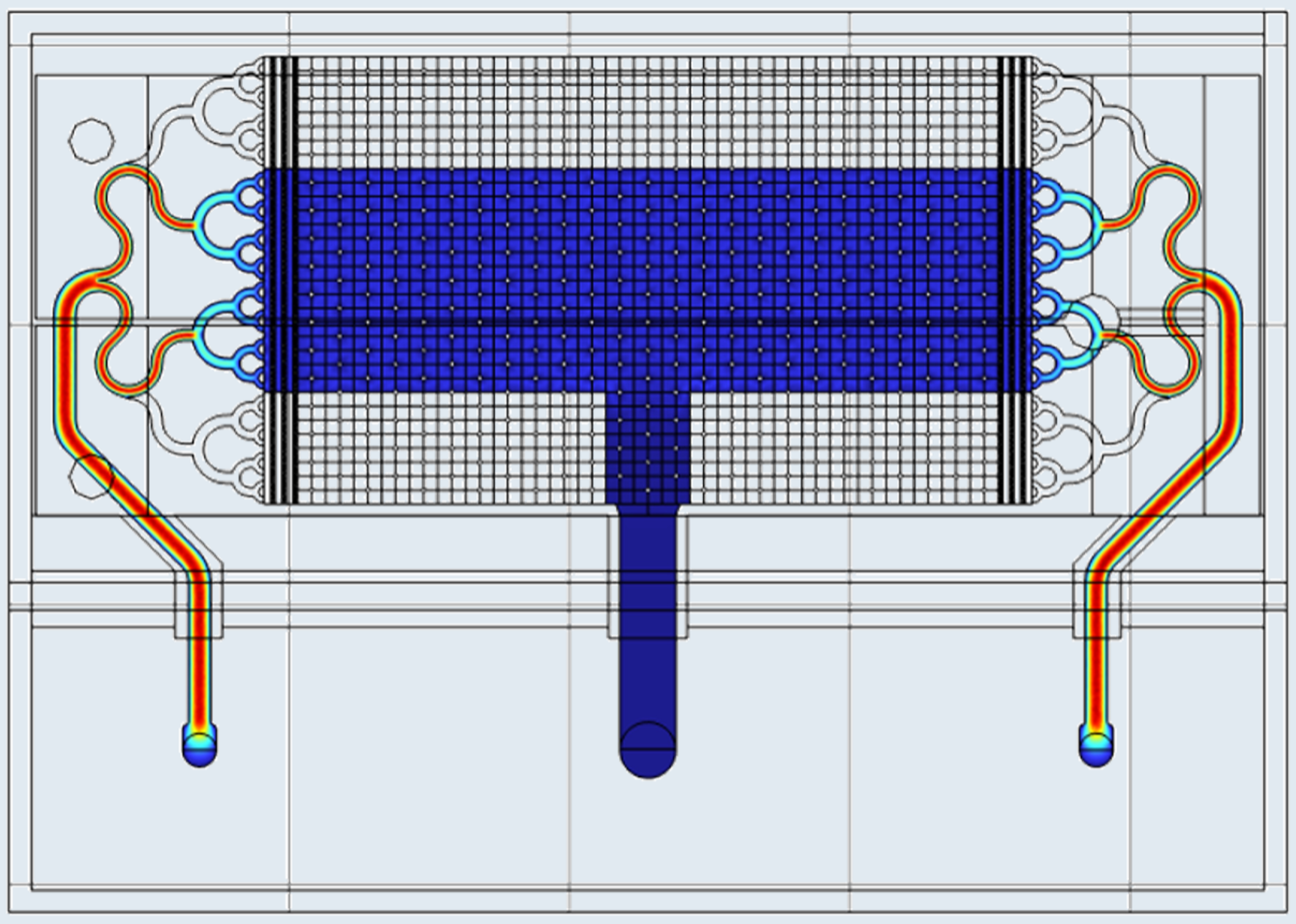

MEMS Gas-Chromatograph Pre-Concentrator Multiphysics Simulation

MEMS Gas-Chromatograph (GC) is a key system for a miniaturized planetary (Mars) atmospheric life detector [1]. A methodology is shown to optimize the pre-concentrator MEMS chip design. The chip absorbs VOCs in Tenax® layer and fast desorbs them by heating. This development was funded by ESA.

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Introduction

The objective of this simulation model is to enhance the thermal behavior of a MEMS Gas-Chromatograph (GC) pre-concentrator of Volatile Organic Compounds (VOCs).
Precise and rapid temperature control is essential for optimal VOC desorption from the Tenax® polymer filling the pre-concentrator chip cavity. By inducing a fast-heating pulse, we release highly time-concentrated VOCs into the carrier gas (Helium) exiting the pre-concentrator, leading to increased accuracy of VOCs detection.

The simulation plays a critical role in estimating the heater geometry, its maximum voltage and current density, thermal time constants, and spatial temperature uniformity within the Tenax® polymer material. The chip design optimization comes with a few challenges i.e. voltage is limited to 28V and current must be lower than the heater electro-migration limit. Tenax® temperature uniformity is reduced by heatsinking of the chip to its surroundings. Chip size is limited due to yield & costs issues. Tenax® target heating is 280-300°C in <5s in >70% volume.

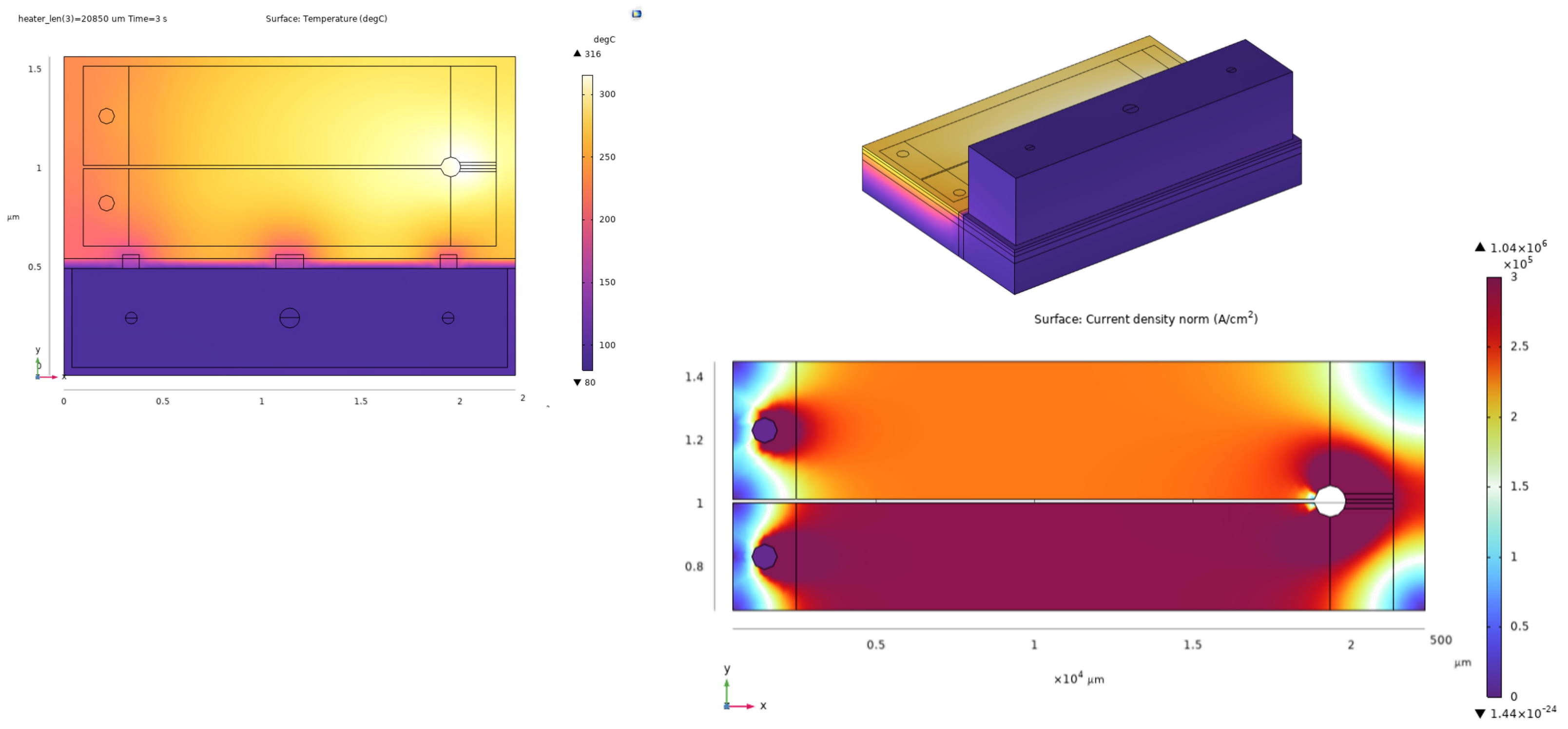

FIGURE 1 (a, b). MEMS pre-concentrator chip temperature, (c): optimized heater current density.

Methodology

Thermal and flow models required experimental validation of material properties of Tenax® porous material pellets. A flow model has been implemented with calibrated parameters based on the heating setup of a cube filled with Tenax®. Gas-flow behavior of Tenax® porous material has been estimated based on literature flow data for a round pipe filled with Tenax® particles and accordingly simulated and calibrated with a model [2, 3]. Selected physics have been included in the chip model: heat transfer in solid and fluids, laminar flow, with porous flow in Tenax® and electrical current in shells (2D-layer) to model the pre-concentrator heater. The selected physics are also coupled together to correctly compute ohmic losses in the heater and non-isothermal flow due to strong thermal gradients in the model as shown in Fig. 1 (a, b).

Results

The model solves in 1h40m on a Linux® Server and helps to quantify the Tenax® spatial (volume) and temporal temperature evolution in form of relative volume histogram snapshots for specific time-slices.
The initial symmetric heater and thermal connection design was delivering 30% of Tenax® temperature uniformity in 20°C range, around the peak. It gave insight how to effectively optimize the asymmetric heater design, its position on chip and resulted in Tenax® heating speed-up reaching a range of 265-285°C in ~2.5s within >64% of the volume (Fig. 2a). The heater is operated at a power of ~27W.
A different Tenax® configuration, based on same chip size and heater improved the Tenax® heating range of 275-295°C in ~3.1s within >84% of the volume (Fig. 2b). Finally, the heater is operating with a current density of ~3E5A/cm2 and well below the limit (Fig. 1c).

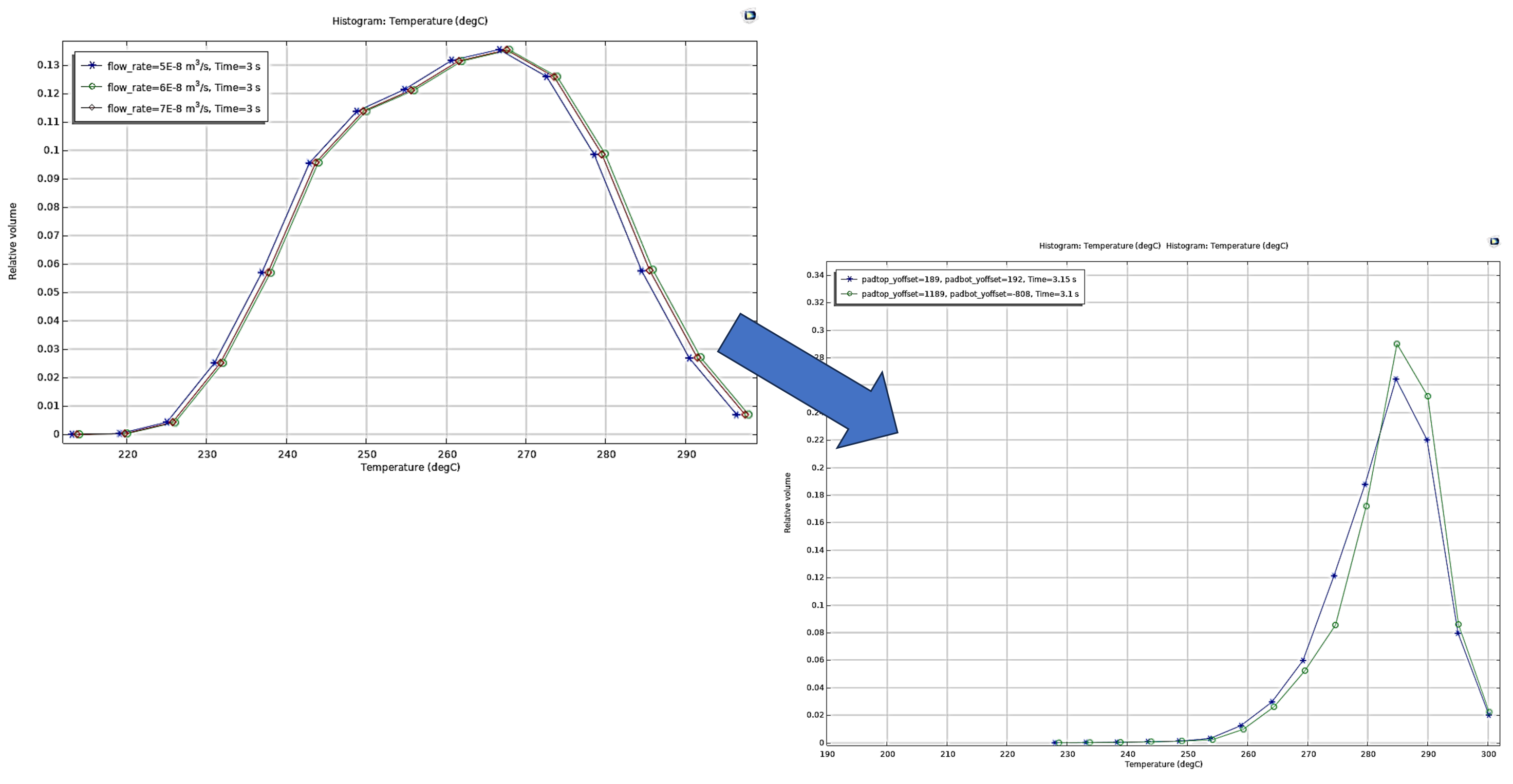

FIGURE 2 (a). Tenax® temperature distribution optimized, (b): Tenax® temperature distribution improved uniformity.

REFERENCES

1. High-performance MEMS-based gas chromatography column with integrated micro heater
https://link.springer.com/article/10.1007/s00542-010-1165-y
2. Tenax® TA Adsorbent Resin Specifications
https://www.sisweb.com/index/referenc/tenaxtam.htm#4
3. COMSOL Blog: Modeling Darcian and Non-Darcian Flow in Porous Media
https://www.comsol.com/blogs/modeling-darcian-and-non-darcian-flow-in-porous-media

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